EFFECT OF GRANULAR INCLUSIONS ON THE CONSOLIDATION RATE OF DREDGED MARINE CLAY

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Abstract
This study investigates the granular inclusion such as sand, palm oil clinker and recycled pavement materials, in conjunction with dredged marine clay from dredging project at Kuala Perlis, Malaysia to improve the consolidation rate. Dredged marine clay (DMC) known as geo-waste because of poor engineering properties. Thus, dredged and dump methods become an option to certain countries without any treatment before dumping it back to open waters. In addition, this method clearly gives the negative potential towards the environment especially the contamination of DMC to the marine ecosystems. Therefore, this study investigated the effect of granular inclusion to accelerated consolidation time and determine whether it can be reuse or not by used the 1D oedometer test. The results showed that the use of granular materials does suggest the increasing of consolidation rate as well as strengthen the soil particles of DMC. Moreover, the effective use of waste granular materials such as palm oil clinker and recycled pavement materials contributes to developing a sustainable society by reducing the huge quantities of solid wastes and establishing a sound environment.

Keywords: *Dredging; Dredged clay; Granular materials; Oedometer; Consolidation rate*

INTRODUCTION

Dredged clay comes from the excavation activities to maintain the shipping channels or development for new structure near the ports. The volume of dredged clay worldwide keeps on increasing because the growth of industrial development and port expansion. It is apparent that increased dredging over the years was accompanied by increased of disposal costs. Dredging costs depend on the equipment, estimated dredged volume, type of dredged materials, disposal distance from the excavation site, time and disposal method. In Kuala Perlis, Malaysia, 937,000 m^3 of dredged clay were generated in year 2016. The dredging cost that needs to be borne by Malaysian Government was RM 20-30 million to deepen the coastal area for tourism purposes (Wan Salim et al., 2012). As such, coastal region plays a significant role in the economic and infrastructure development as well as the tourism industry of the country (Lee, 2010). According to Anuar (2015), 60 % of the population in Malaysia lives near the coastline. There are 107 ports in Malaysia including Sabah and Sarawak (Khalid et al., 2011). Based on Marine Department of Malaysia, a total of 7 major federal ports namely Port Klang, Johor, Tanjung Pelepas, Kuantan, Penang, Bintulu and Kemaman. The number of ports and harbours would clearly influence the frequency of dredging activities at coastal areas. Despite of dredging cost is high, it could be a hindrance to port authorities for regular maintenance to support the continuation and further development of harbours (Kaliannan, 2016).

Dredging activities have increasingly been viewed as bringing potential adverse effects on the environment. It is particularly so because of the disposal of unwanted dredged materials at sea. This method is a frequent practice in dredging works. It causes the environmental problems in short and long terms in both marine and estuaries environments. The potential effects of dredging, i.e. interference with marine and river traffic, coastal erosion, saline wedge intrusion, noise generated by the dredging plant and high turbidity parameter (Bray et al., 1997). On the other hand, Manap and Voulvoulis (2015) reported that the sediments can cause changes in seabed and affect the marine lives with contamination. Dredged clay is considered as soft soils (geo-waste) because of the poor engineering properties. It is high in compressibility, high in water content, low in load bearing capacity and low permeability. However, the dredged clay can be reused after the treatment based on the soils properties such as backfill materials, landfill cover, beach nourishment, land reclamation and wetland restoration (Shahri and Chan, 2015).

The disposal of waste products from various industries may be a challenge these days. It has been reported that most of the waste materials contribute to environment pollution since of their non-biodegradable characteristics (Sen and Mishra, 2010). It been supported by Cabalar et al. (2016) that the construction industries are the main contributors produced huge pile of waste. Therefore, the environmental consequences of reusing these materials should be altogether explored to create sustainable and eco-friendly society. So, palm oil clinker (POC) and recycled pavement materials (RPM) are used as waste granular materials as well as sand. The present study focused on investigating the basic characterization of dredged clay and the effect of several types of granular materials inclusion in consolidation rate of dredged clay.

EXPERIMENTAL WORK

Materials

The dredged clay studied in this paper were dredged in 2015 from Kuala Perlis jetty. The dredged clay is black, liquid and somewhat unpleasant due to the presence of organic matter as in Figure 1(a). The dredged clay was retrieved from the seabed at about 4 – 6m in depth. The dredged clay samples were taken into the storage tank with doubled layer of plastic sampling bags from the dredger manually to prevent the moisture loss during transportation back to laboratory. Granular materials used in this study are sand, palm oil clinker and recycled pavement materials. All the granular materials used are in same particles size ranged between 2 – 2.36 mm.

POC is produced from the incineration process of oil palm shells and fibres. This waste product is collected from inside the boiler. The POC looks like a porous stone in gray colour (Figure 1b). The clinkers are usually flaky and irregularly shaped. The broken edges are rough and spiky. The POC for this study was collected from a palm oil mill factory at Pasir Gudang, Johor. RPM (Figure 1c) was collected from roadways at Gemencheh, Negeri Sembilan during the refurbishment work. RPM is a processed material containing aggregates coated with bitumen binder generated when a bituminous pavement is removed for construction or resurfacing up to about 100 mm depth. The material contains of aggregates coated with bitumen from the base course layer. It typically had lower bitumen binder content.

(a) (b) (c)

Figure 1. (a) Dredged clay; (b) Palm oil clinker; (c) Recycled pavement materials

Methods

An experimental programme was performed on raw sample of DMS and DMS mixed with various waste granular materials such as recycled pavement materials (RPM) and palm oil clinker (POC) to evaluate the changes in engineering properties and the potential granular inclusion to increase the consolidation rate. The proportion of sand and DMS content is determined in percent with respect to dry weight of soil. The purpose of mixing with kitchen mixer was to make sure the samples are uniform. The homogenous mixture was then transferred into a metal ring of oedometer mould (75 mm dia. x 20 mm thick). Oedometer test was carried out by following the procedure prescribed in BS 1377 (1990). The ring containing the homogenous specimen was placed between the two porous stones, one at the top of the specimen and another at the bottom. The specimens were kept under water during the test. Incremental vertical stress was applied as follows: 5, 12.5, 25, 50, 100, 200, 400 and 800 kPa, with each load being maintained for 24 hours.

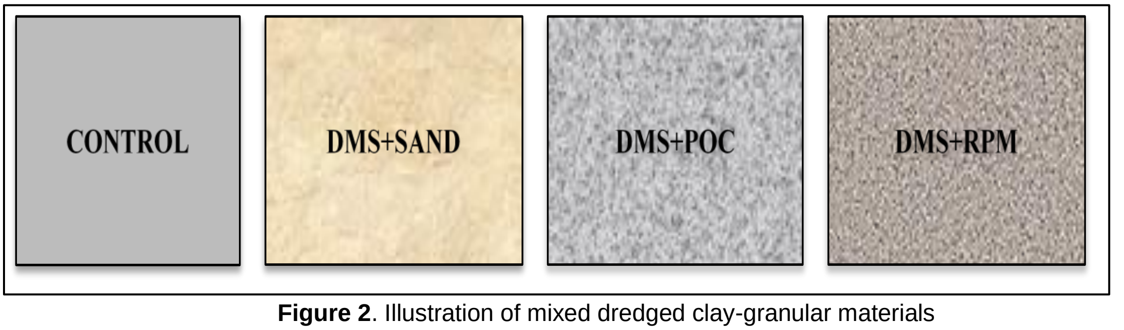


Figure 2. Illustration of mixed dredged clay-granular materials

RESULTS

Characterization of dredged clay and granular materials

The main physical characteristics of dredged clay are reported in Table 1. The initial water content, measured by oven-drying method, is about 218.07% at 110°C. Based on the Atterberg limit tests, the values of plastic and liquid limits are 55.80 % and 66.50 % respectively. According to Unified Soil Classification System (USCS), the soil is classified as high plasticity silt (MH). The obtained specific gravity value for this soil is 2.68. Figure 3 shows the particle size distribution of dredged clay and granular materials. Grubb et al., (2010) stated that the water content of DMS is in the range of 100 % - 200 %. It is proven that the DMS in liquefied form and slurry. Each location of dredging gives different value of water content because it has a different soil profile with distinct attributes of its own.

In terms of the chemical properties, the pH value for DMC is 8 which the pH concentration is more than 7. Thus, conclude that the soil is alkaline and in range with average seawater (Chester and Jickells, 2012). Figure 3 shows the dredged clay is finer than sand, POC and RPM. POC and RPM were proven to be coarser than sand. Based on USCS, POC and RPM particles are classified as well-graded gravel (GW), whereas sand particles are classified as well-graded sand (SW). In addition, the specific gravity for sand, POC and RPM are 2.65, 2.17 and 2.39 respectively. Specific gravity values for POC and RPM are lower than the typical specific gravity of natural granular materials (2.65-2.70). Lower Gs of RPM is attributed to bitumen binder coating, whereas POC is due to the texture that have many voids.

Table 1. DMC characterization for Kuala Perlis

Properties	Dredged clay	
Initial water content, w_c	218.07 %	
Specific gravity, G_s	2.68	
Liquid limit, LL	66.5 %	
Plastic limit, PL	55.8 %.	
Plasticity index, PI	10.69	
pH	8.0	
W_C/LL	3.27LL	
Soil classification (USCS)	MH	
	Sand	1%
	Silt	38 %
	Clay	61%

Table 2. Properties of granular materials

Properties	SAND	POC	RPM
Specific gravity, G_s	2.65	2.17	2.39
Soil classification (USCS)	SW	GW	GW

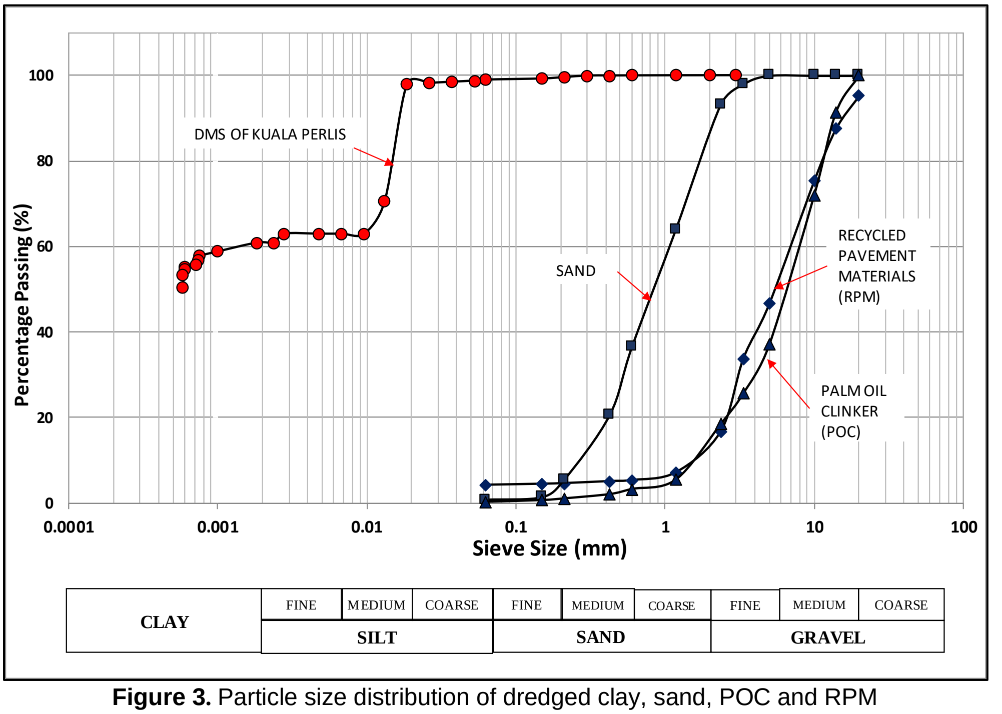


Figure 3. Particle size distribution of dredged clay, sand, POC and RPM

Effect of granular inclusion on consolidation rate of dredged marine clay

Figure 4 shows the one-dimensional compression curves of DMC mixture with granular materials. Regardless of the types of granular materials, a general observed trend was that the strength increased with the mixture of sand, palm oil clinker and recycled pavement materials. The compression curves of specimens with DMC mixed fold into one at last stage in the tests. There was clearly improvement in the settlement reduction for the DMC mixed rather than the DMC only. DMC-RPM and DMC-SAND are slightly more compressible than DMC-POC. It is possibly because both POC have a pozzolanic reaction of silicon oxide (SiO_2) and Aluminum Oxide (Al_2O_3) which give a further increase of strength reaction (Rahman et al., 2014). On the other hand, the angularity and porosity surface texture of POC are typically more compressible because the sharp edges in the angular particles tend to be overstressed during increasing in the confining pressure. However, the DMC-SAND, DMC-POC and DMC-RPM mixture samples exhibited greater improvement on the strength and stiffness of DMC. This suggests that, at the same vertical stress, the DMC alone without any granular materials are more compressible than the granular inclusion.

In addition, the DMC mixed with granular materials shows a good drainage ability by fasten the consolidation time. The usage of granular materials as a replacement of cement eventually minimize the emission of CO_2 in the future. Figure 5 shows the time plot for all the homogenous mixture at 5 kPa, 12.5 kPa, 25 kPa and 50 kPa. As expected, all the sample mixture shows the same path at 5 kPa till reach the end of primary consolidation. Especially for the DMC-SAND show more good drainage than the DMC-RPM and DMC-POC at all stage of vertical stress. There has high possibility that the physical properties of granular materials influence the drainage flow. For example, RPM still coating with the bitumen while the POC have many of voids. Despite have different physical characteristic, the mixtures still give an improvement on the DMC.

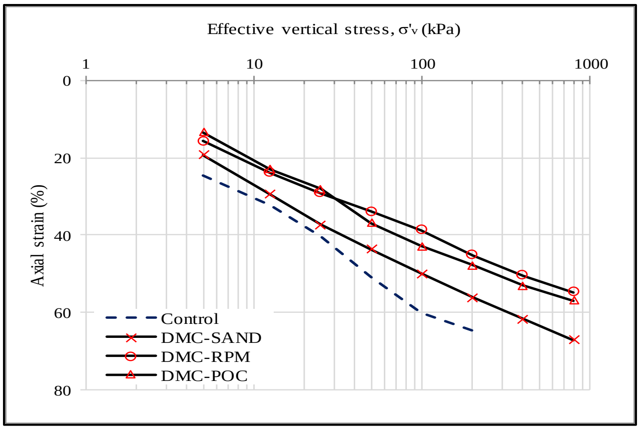
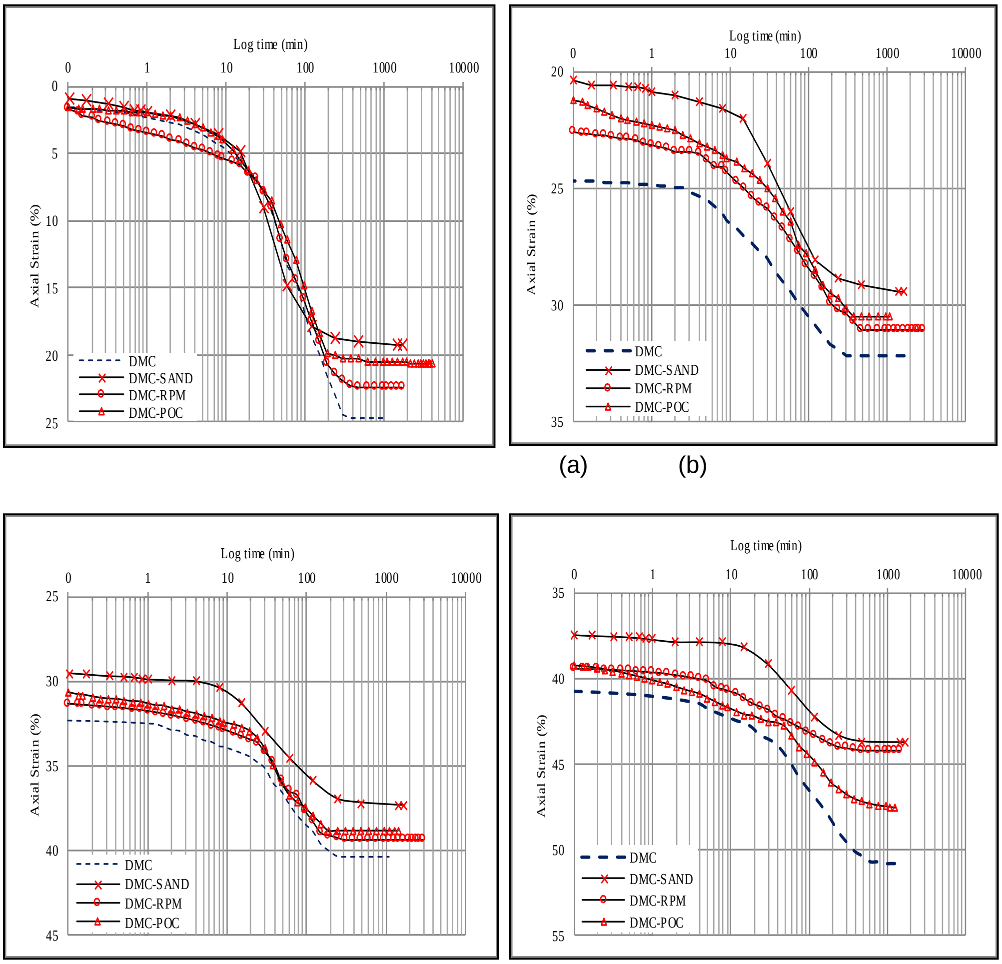


Figure 4. Compression curves of dredged marine clay-granular materials



(a) (b)

(c) (d)

Figure 5. Time plot for homogenous-granular materials (a) 5 kPa, (b) 12.5 kPa, (c) 25 kPa and (d) 50 kPa

CONCLUSIONS

Based on the results presented in this paper gives an overview of the current research on the effect of granular inclusion towards the consolidation rate of dredged clay. Higher compressibility of DMC is attributed to the high-water content of soil particles contact upon loading. However, the inclusion of granular materials shows a good drainage ability and reduce the settlement. This highlights the possibility of waste materials act like cement as a binder. This could reduce of usage the cementation on the soil for the future. This will help to reduce environmental impact and being more economical. The disposal of the POC and RPM in landfill may harm the environment. So, if the waste materials include dredged clay is reused, it could help to reduce the environmental effects.

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